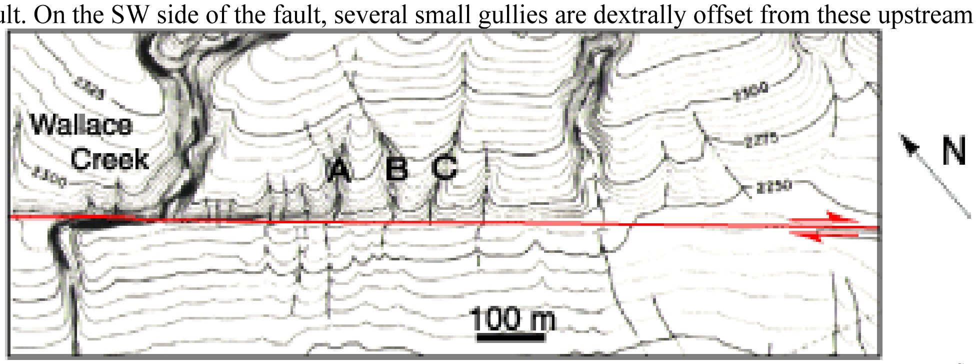
Slip Behavior of Faults through Several Earthquake Cycles
Award Number 99-HQ-GR-0043

Kerry Sieh
1200 E. California Blvd.
California Institute of Technology
Mail Code 100-23
Pasadena, CA 91125
Tel: 626-395-6115
Fax: 626-564-0715
sieh@gps.caltch.edu

NEHRP Element: II
Key Words: Paleoseismology, Trench Investigation, Fault Segmentation, Quaternary Fault Behavior

Investigations Undertaken

The primary purpose of this study is to document the amounts of recurrent earthquake slips at a single location to look how similar is the slip through earthquake cycles. One of the best place to determine if a fault segment experiences similar amount of slip through many earthquake cycles is a 100-meter section along the Carrizo segment of the San Andreas fault, just a few hundred meters southeast of Wallace Creek (Figure 1). There, very small channels about a half-meter deep are cut by the simple, narrow, rectilinear trace of the San Andreas fault. Three such small channels (labeled A, B, and C) have been incised several meters into the Pleistocene alluvial fan NE of the fault. On the SW side of the fault, several small gullies are dextrally offset from these upstream channels.



Contour interval = 5 feet

Fig.1a Topographic map of Wallace Creek and nearby small offset streams.

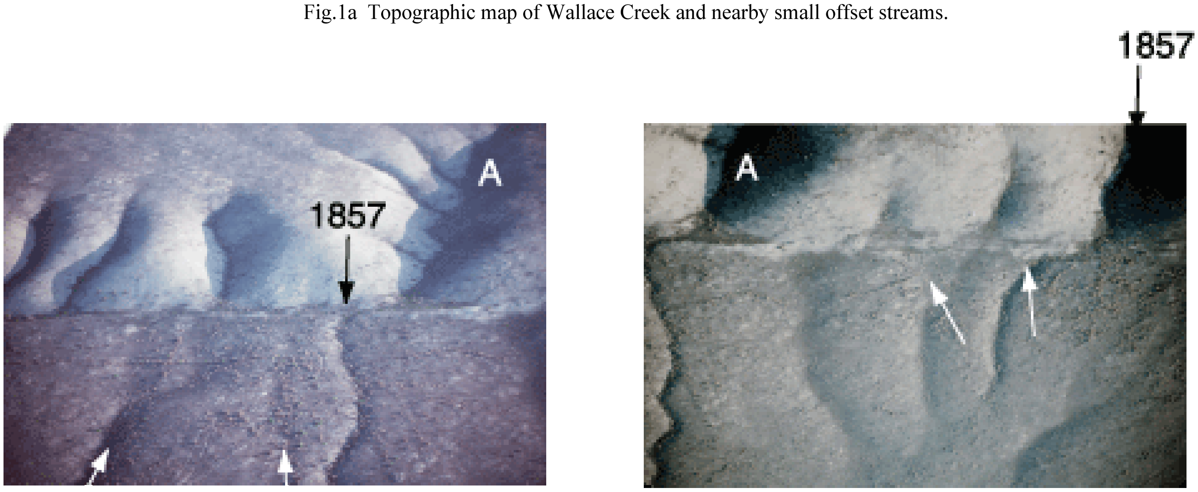


Fig.1b Oblique aerial photos of small channels A and B and their offset downstream segments.

We first made a geologic map of the offset gullies in the area we intend to excavate. In the second phase, we are making 3D trenches across the offset creeks on both sides of the fault and map the trench exposures. During the last year, we completed 3-D excavations and mapping of the channel “h”, the youngest offset downstream channel, and nearly completed excavations and mapping of the upstream channel “B”. Figure 2 shows the traces of the principal excavation walls on a map view. In each trench cluster, the initial trench was parallel to and ~ 4-5meters from the fault. Subsequent faces were cut progressively closer to the fault, by an increment of 50cm or less, as shown on figure 2.. Sequential excavations and logging of the trench walls enable us to keep track of the variation of the shape of the buried channels along their thalweg. These successive trenches also provide us with a record of the multiple cutting and filling stages within individual channel, which shows a complete evolving history of the channel morphology.

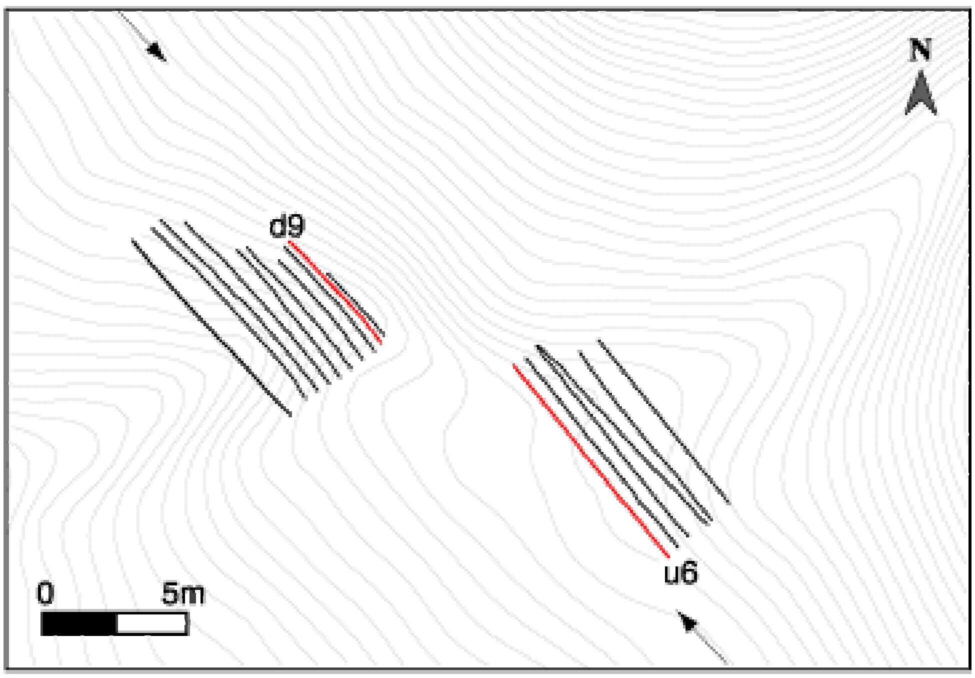


Fig.2 Traces of the principal excavation walls. The red lines indicate the location of the exposures shown in Figures 4 and 5. Arrows indicate the approximate location of the fault.

Results

<u>Mapping of the surfacial geomorphic and geologic features:</u>

Our map of the area around channels B and C (Figure 3) reveals that both channels have a rich history of deposition, erosion and offset. The youngest incision of the upstream portion of channel B appears to correlate with channel “h,” downstream from the fault, and post-1857 alluviation has partially filled the channel segment, but has not fully buried it.

Northwest of channel “B”, downstream from the fault, deposition of alluvial fans appears to have alternated with incision (Fig.3). Aside from the channel “h”, which was dextrally offset about 9 m from “B” in 1857 earthquake, there are two broad beheaded channels (“a” and “e”) occur about 55m and 30 meters from, but used to line up with “B”. Between the two channels, however, the topography suggests an alluvial fan, ”c”. The contour lines suggest that the fan is about 30 cm thick and about 10 meters wide at the fault. Because this width approximately equals the width of a small channel B fan immediately upstream from the fault, we suspected from topo, alone, that these two fans were correlative. If so, they would be offset about 45 meters.

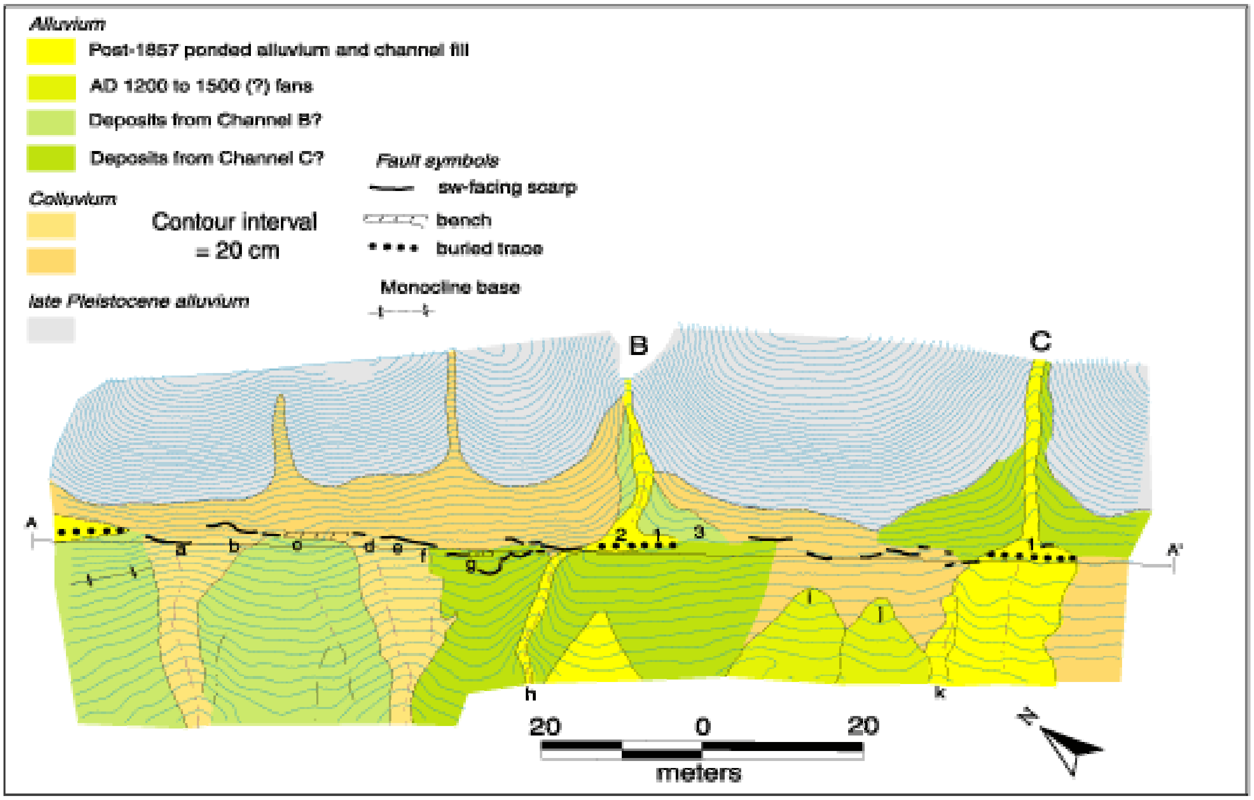


Figure 3. Map of small offsets southeast of Wallace Creek

The flaring of the two neighboring offset channels ("a" and "e") suggests that their history is not simple. But, from the geomorphology alone, one cannot construct a unique offset history. For example, the channel farthest northwest could have been cut initially perpendicular to the fault, directly downstream from channel B. Following about 10 meters of offset, the southeastern margin of the channel might have been modified by incision of a gully ("b") diagonally across the fault, from channel B into the original downstream gully. Alternatively, this diagonal margin of the gully might be the edge of an alluvial fan that partially filled the near-fault part of the gully. We anticipate that an excavation will allow us to reconstruct the history of formation of the gully by revealing the relationship of channel scours and fills, colluvial deposits and alluvial fan deposits.

Contours across the middle of the large gully about 30 m northwest of channel B are nearly fault-parallel; thus either a buried central channel ("e") is offset about 30 m, or there is no offset feature. About 28 m of offset may have accrued since channel B cut a subtle gully across the fault at "f." Point "g" could be the apex of an alluvial fan, offset about 21 m from channel B; but we suspect the bulge in contours there is the result of erosion of channel "h" into a broad alluvial fan.

In short, the surfacial mapping suggests the multiple phases of channelization at channel "B". The downstream half of the channels are sequentially moved away from the source channel after each earthquake and subsequently abandoned. Thus this site has the potential to record the offset of several individual earthquakes if not all. The geomorphic mapping bears the intrinsic ambiguity in terms of offset measurement; the morphology of channels would become more and more subdue, or blurred with time, due to later bioturbation and colluvial burial. Nevertheless, this can be compensated when combined with shallow excavation.

<u>Trench Exposures of the downstream channel "h"</u>

Fig.4 is the log of a representative cut, whose location on a map view is shown as the red line labeled "d9" in fig.2. A solitary channel cuts into a bioturbated sequence of alternating sandy and gravely lenses and massive homogeneous matrix-supported gravely sand and silt layers (Fig.4). A pedogenic carbonate horizon in the older (uncolored) deposits suggests that these deposits are several thousand years old, since in this region such concentrations of soil carbonate are only found in early Holocene or older deposits (Sieh and Jahns, 1984). The lone downstream channel in Fig.4 is narrow and deep, and its thalweg is very well defined. The uppermost layer is not cut by the fault; rather, it diverges to the southwest, through the shallow declivity that subparallels the fault. This demonstrates that no offset of the channel occurred in the period that included cutting and alluvial filling of the channel. Offset occurred between deposition of the majority of the channel fill and deposition of the uppermost few cm of colluvial fill. The lack of any rounding and re-faulting of the topography at this horizon demonstrates that the offset occurred within a time period too short to allow any appreciable degradation of the scarp. Thus, the offset represents either a single seismic event or multiple events no more that a few years apart. The most plausible conclusion is that this offset represents the 1857 event.

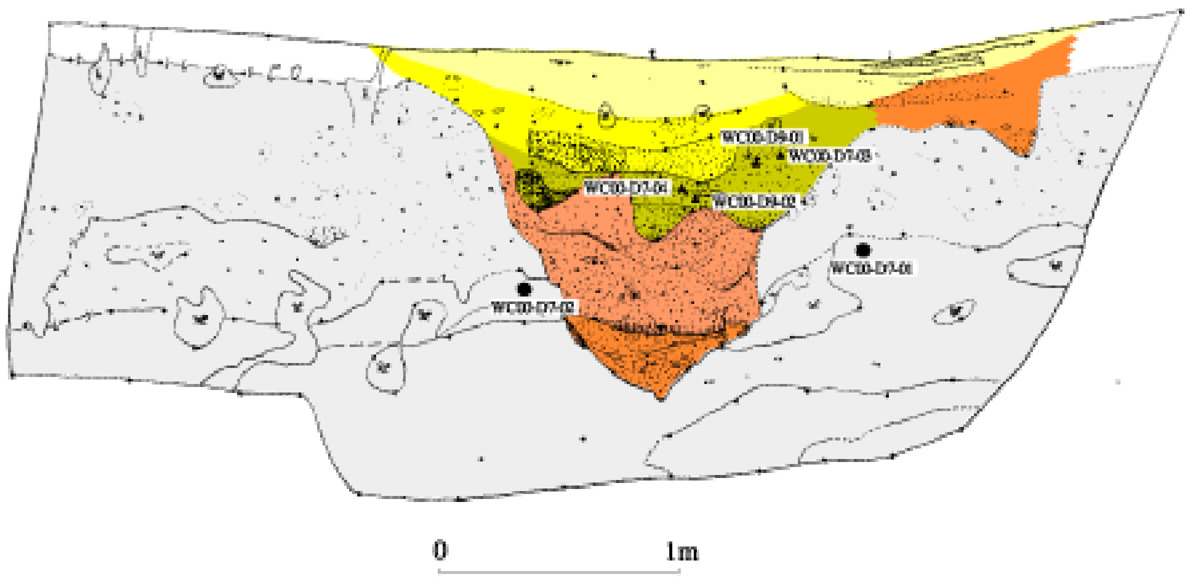


Fig.4 The trench log of a representative excavation wall d9, downstream from the fault, looking upstream. We put charcoal samples from other walls at the corresponding position on this cross-section to show the stratigraphic distribution of the samples. Bioturbated regions are left blank.

<u>Trench Exposures of the upstream channel</u>

We have now logged 6 cuts on the upstream side of channel “B”. The cross-sections of the upstream channel document a series of nested channels (fig.5, whose location is labeled as "u6" in fig.2). The shape of the youngest cut just upstream is very similar to its shape just downstream. Unlike the downstream channel, the youngest upstream channel has a prominent lens of silty fine sand, overlain by coarser sandy and gravely alluvium (labeled “5” and in red color in Fig.5). The fines are suspended loads that settled from muddy water in a 0.5m-deep pond. The pond pooled above the partially alluviated, pre-1857 channel, after the 1857 event brought a ridge in front of channel. Filling of the upstream channel by coarser sandy gravel occurred later.

It is very significant that the upstream channel fill contains many older cuts and fills as well as the youngest one. Eight lenses of fine sand and silt (1a to 5 in Fig.5) are prominent components of these older channels. These suspended-load beds vary in width, thickness and shape. They formed upon several immediately pre-offset channel floors.

The oldest channel contains no coarse basal debris; the suspended-load lens (1a) lies almost directly atop the cut. This suggests that the channel was blocked when it was still devoid of fill. The concavity of the suspended-load deposit indicates the ponded water behind the shutter ridge was about 0.5m deep. The best candidate for a downstream match to this oldest channel is the one farthest northwest on Figure 3.In that case the cumulative offset would be about 55 m.

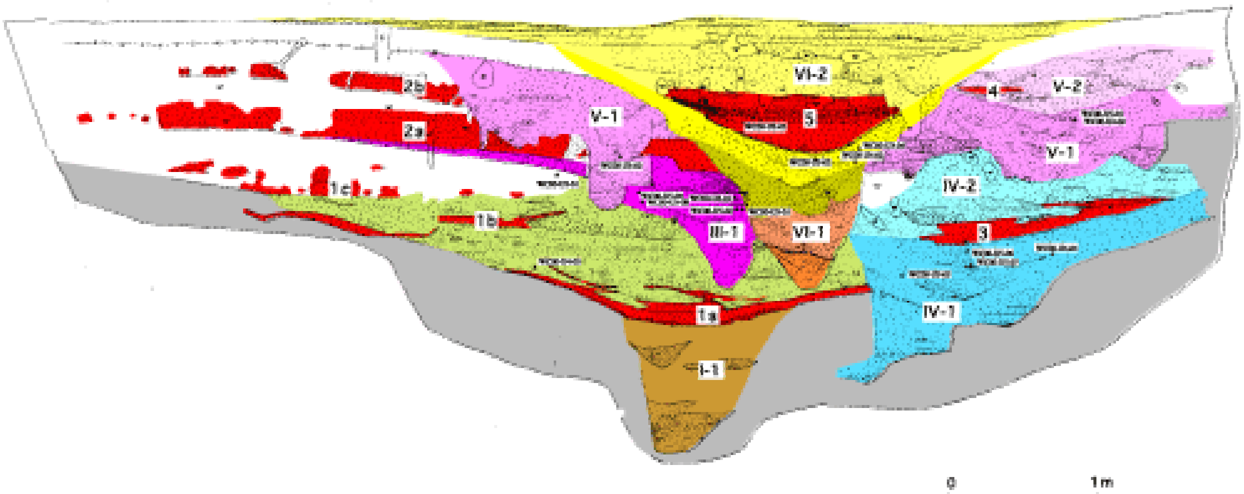


Fig. 5 Map of representative excavation wall u6, upstream from the fault, looking downstream. The units in red are suspended load, ponded behind shutter ridges after major right-lateral slip. Note the multiple episodes of channelization. The channel deposits in Fig.4 are colored the same as the corresponding units of the youngest channel in Fig.5. We put charcoal samples from other walls at the corresponding position on this cross-section to show the stratigraphic distribution of the samples. Bioturbated regions are left blank.

Upstream channel fills of intermediate age are broader than either the 1857 or the oldest channel fill. The remnants of their suspended-load lenses are 2.0 to 4.5 m wide. This suggests that immediately prior to emplacement of their shutter ridges, these channels were broader and shallower than the oldest channel and the 1857 channel. We suspect that these intermediate channels correlate with the broad, forked downstream channel that appears 20 to 40 m to the NW (Fig. 3).

Slip in 1857 by Matching Channels

The dextral and vertical offsets in 1857 earthquake can be calculated accurately by matching the thalweg of the offset channels on both sides of the fault.

The base of the channel "h" runs into the fault at a high angle. Fig.6 shows the trace of the excavated portion of the thalweg in map view. In fact, all channel deposits and walls, except for the uppermost part of the pale yellow lens of organic silty loan, run abruptly into the fault. This offset represents the 1857 event. The youngest upstream channel matches the downstream channel "h" in trench exposures, even details of its initial alluvial and colluvial fill match those downstream. The thalweg of this segment of the channel also runs directly into the fault. The dextral offset of the thalwegs across the fault is 8.3 +- 0.1m; as shown by the offset gray circles on two sides of the fault in Fig.6; the vertical offset is 0.1 +- 0.05m. This slip is slightly smaller that the 9.5 +- 0.5m previously inferred from the geomorphology alone (Sieh and Jahn, 1984); this amount of displacement is localized in a narrow fault zone of ~1m-wide or less. We did not find secondary fault traces during our excavation.

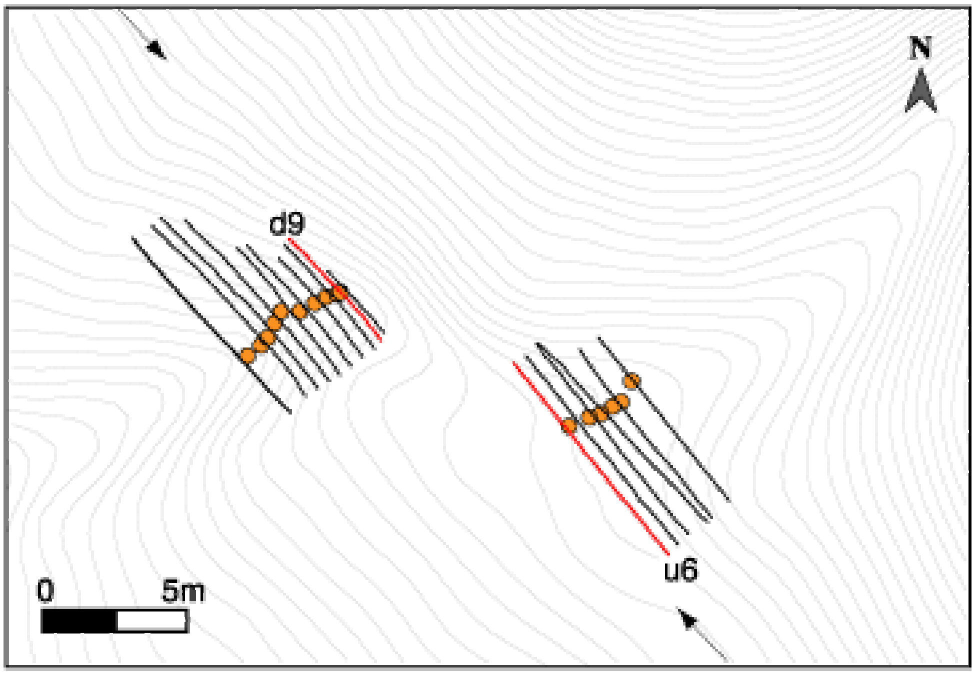


Fig.6 Traces of the principal excavation walls. The red lines indicate the location of the exposures shown in Figures 4 and 5. The circles show the trace of the thalweg of the channel that was offset in 1857. This thalweg is offset 8.3 +-0.1 m. Arrows indicate the approximate location of the fault.

Non-technical Summary

The issue we want to address in this project is our poor understanding of how fault slip repeats through many earthquake cycles. Are the earthquakes characteristic or do they vary from event to event? How the slip per event could be incorporated into temporally clustered recurrence behavior of earthquakes as widely held? The answers to these questions have both theoretical and practical significance. They will help us to better understand how strain is accumulated and released on faults, hence will improve our earthquake hazard evaluation.

While most of the previous works on paleoseismology focus on the temporal recurrence of earthquake, the important and indispensable investigation on slip per event is missing, which hinder our complete understanding of earthquake repetition. Part of the reason is the difficulty to find locations where multiple slips were recorded. One of the most promising places for this purpose is located on the Carrizo segment of the San Andreas fault, where multiple beheaded channels were moved sequentially away from the source channel and abandoned. While later burial and bioturbation made the channels subdued inducing considerable uncertainty, shallow excavation will enable us to locate accurately the positions of those channels. By matching the corresponding channels on both sides of the fault, we will be able to document the amount of slip for each individual earthquake during the last thousand years, which will help us to estimate both the magnitude and timing of the next earthquake.

Reports Published

Because this project is still in progress, no publications have been generated yet.